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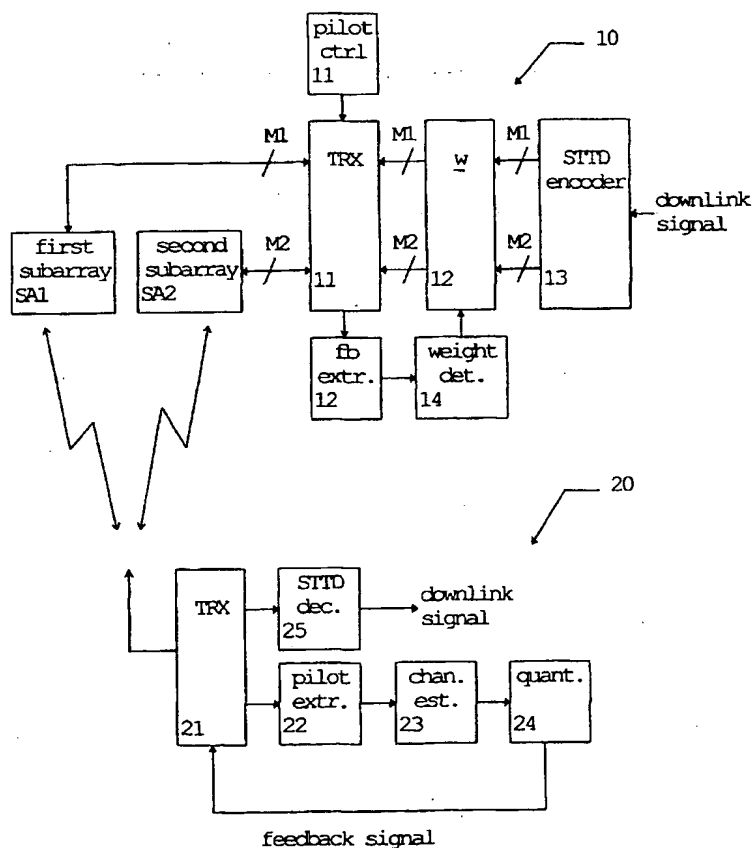
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(54) Title: TRANSMIT DIVERSITY METHOD AND SYSTEM

(57) Abstract: The present invention relates to a method and system for transmitting in a wireless communication system, a transmission signal divided into at least two signal parts by using transmission beams of at least two subarrays (SA1, SA2) of an antenna array. The transmission beam of at least one of the at least two subarrays (SA1, SA2) is at least in part controlled based on a feedback information received from the receiving means (20). Thus, several beams are generated using an antenna array with more than two antennas, wherein an open-loop diversity is used to split the transmission between the beams, and a closed-loop feedback-based diversity is used to optimize the beams, as well as possibly the division of power between the beams. Thereby, the amount of feedback can be controlled so as to achieve significant feedback gain in a multi-antenna transmission even with non-maximal amounts of feedback.

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

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Transmit diversity method and system

FIELD OF THE INVENTION

5   The present invention relates to a transmit diversity
method and system for a wireless communication system, such
as the Universal Mobile Telecommunications System (UMTS)
comprising a transmitting element and at least one
receiver.

10

BACKGROUND OF THE INVENTION

Wideband Code Division Multiple Access (WCDMA) has been
chosen as the radio technology for the paired bands of the
15 UMTS. Consequently, WCDMA is the common radio technology
standard for third-generation wide-area mobile
communications. WCDMA has been designed for high-speed data
services and, more particularly, Internet-based packet-data
offering up to 2Mbps in indoor environments and over
20 384 kbps for wide-area.

The WCDMA concept is based on a new channel structure for
all layers built on technologies such as packet-data
channels and service multiplexing. The new concept also
25 includes pilot symbols and a time-slotted structure which
has led to the provision of adaptive antenna arrays which
direct antenna beams at users to provide maximum range and
minimum interference. This is also crucial when
implementing wideband technology where limited radio
30 spectrum is available.

The uplink capacity of the proposed WCDMA systems can be
enhanced by various techniques including multi-antenna
reception and multi-user detection or interference
35 cancellation. Techniques that increase the downlink

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capacity have not been developed with the same intensity.
However, the capacity demand imposed by the projected data
services (e.g. Internet) burdens more heavily the downlink
channel. Hence, it is important to find techniques that
5   improve the capacity of the downlink channel.

Bearing in mind the strict complexity requirements of
terminals, and the characteristics of the downlink channel,
the provision of multiple receive antennas is not a desired
10   solution to the downlink capacity problem. Therefore,
alternative solutions have been proposed suggesting that
multiple antennas or transmit diversity at the base station
will increase downlink capacity with only minor increase of
complexity in terminal implementation.
15

The transmit diversity concept adopted for the FDD
(Frequency Division Duplex) mode of third generation WCDMA
system in the 3G standardization is currently being
optimized for the case of two transmitting antennas at the
20   base station.

In case of a so-called open-loop mode, a space-time block
code is applied for the two transmitting antennas. The
channel symbols are divided into two-element blocks which
25   are transmitted from a first and second antenna,
respectively, at successive time instants. These symbols
are transmitted using the same spreading code. The receiver
then uses a linear orthogonal processing based on the
estimated channel coefficients to detect the transmitted
30   symbols.

Alternatively, in case of a so-called closed-loop mode, a
weight information is fed back from the terminals to the
base station to approximate matched beamforming. Fig. 1
35   shows an example of such a closed-loop or feedback mode for

a downlink transmission between a base station (BS) 10 and
a mobile terminal or mobile station (MS) 20. In particular,
the BS 10 comprises two antennas A1 and A2, and the MS 20
is arranged to estimate the channel on the basis of pilot
5   channel signals used to probe the downlink channel and
transmitted from the two antennas A1 and A2. Then, the MS
20 feeds back the discretized channel estimate to the BS
10. The antennas (or antenna elements) A1 and A2 are spaced
sufficiently close to each other, so that the propagation
10   delays between each of the antennas A1 and A2 and the MS 20
are approximately identical (within a fraction of a
duration of a chip of the WCDMA spreading code). This is
important in order to maintain downlink orthogonality in a
single-path channel. Naturally, it is desired to develop a
15   robust and low-delay feedback signaling concept.

Transmit diversity techniques provide a low-cost solution
to increase downlink capacity in third generation systems.
A number of different transmit diversity concepts have been
20   developed. Both open and closed-loop concepts have
significant merits in different environments and with
different service assumptions.

In WCDMA, different modes have been suggested for the
25   closed-loop concept which is optimized for two antennas. In
the Selective Transmit Diversity (STD) mode, one bit per
time slot is used to signal the "best" antenna from each
terminal. The MS 20 estimates channel coefficients from
common pilot signals (antenna or beam specific), selects
30   the stronger antenna (two possibilities), and sends the
index to the BS 10 using a 1.5 kbps subchannel. Thus, a
simple dedicated channel estimate can be derived from
continuous common channel estimates. In the STD mode, the
bit length of the feedback signaling word is one bit. The
35   feedback bit rate is 1500 bps and the feedback signaling

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word is used for controlling the power supplied to the
antennas A1 and A2.

Furthermore, modes 1 and 2 (referred to as Transmission
5   Antenna Array (TxAA) modes) are suggested with a slower
feedback link, where feedback weights used for controlling
power and/or phase of the transmission signals of the
antennas A1 and A2 are modified after a certain number of
slots. In particular, a quantized feedback is signaled to
10   the BS 10 using the 1.5 kbps subchannel. In mode 1, the
possible Tx feedback weights are selected from a QPSK
constellation. In mode 2, the possible Tx feedback weights
are selected from a 16-state constellation.

15   Fig. 2 shows a table indicating characteristic parameters
of the above modes. In particular, N_{FB} designates the
number of feedback bits per time slot, N_W the number of
bits per feedback signaling word, Na the number of feedback
bits for controlling an amplification or power at the
20   antennas A1 and A2, and Np the number of feedback bits for
controlling a phase difference between the antennas A1 and
A2. As can be gathered from the table of Fig. 2, one bit is
fed back per time slot in each of the feedback modes.

25   In the Tx AA mode 1, the feedback signaling word comprises
two bits, and an update is performed after both feedback
bits have been received, i.e. after two time slots. The
feedback signaling word is only used for controlling the
phase difference between the two antennas A1 and A2.
30

In the Tx AA mode 2, the bit length of the feedback
signaling word is four, and an update is performed every
four time slots. In particular, one bit of the feedback
signaling word is used for controlling the amplification

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(power) at the antennas A1 and A2, and three bits are used
for controlling their phase difference.

The required channel estimates are obtained e.g. from the
5 common pilot channel signal transmitted with a known power
from each antenna. In WCDMA systems, rather accurate
estimates can be obtained by using the common channel
pilots (CPICH) transmitted continuously from the two
antennas A1 and A2. The feedback information can be
10 transmitted in the Feedback Signaling Message (FSM) as a
part of the FBI field of the uplink dedicated physical
control channel (DPCCH)

It is to be noted that the STD mode may be implemented in
15 an analogous manner in the beam domain. In this case, the
MS 20 signals to the BS 10 whether to rotate channel
symbols transmitted from the antenna A2 by 180°. In this
case, the BS 10 transmits simultaneously from both antennas
A1 and A2. Thus, the phase difference between the antennas
20 A1 and A2 is switched between 0° and 180° in response to
the feedback value.

In the TxAA modes 1 and 2, the MS 20 transmits estimated
and quantized channel parameters to the BS 10 which then
25 weights the transmitted signals accordingly. Thus, a higher
resolution than 180° (as provided by the STD mode) can be
achieved. The MS 20 selects the Tx weight (or Tx beam) from
4 or 16 different constellations, respectively.

30 As regards the table of Fig. 2, it is to be noted that an
equal power is applied to the antennas A1 and A2 in each
case where Na = 0. Furthermore, the antennas A1 and A2 are
uniquely defined by their respective pilot codes of the
CCPCH (Common Control Physical Channel) of the UMTS. The
35 derived amplitude and phase applied to the antennas A1 and

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A2 is called a weight and the set of weights is grouped
into a weight vector. Specifically, the weight vector for
the present case of two antennas is given by

$$\underline{w} = \begin{bmatrix} \sqrt{PA1} \\ \sqrt{PA2} \cdot \exp(j\pi\Delta\varphi/180) \end{bmatrix}$$

wherein $\Delta\varphi$ denotes the phase difference (phase weight) fed
back to the BS 10. If more than two antennas, i.e. an
antenna array, is used, the dimension of $\underline{w}$ becomes larger
than two. In this case, a directional antenna may be
achieved by using relative phases between antennas. The
estimated phase of the feedback signal in the complex plane
is then used for controlling the transmit direction.

Both TxAA modes 1 and 2 rely on the use of dedicated
pilots. As it is possible that some future frame formats do
not include dedicated pilots, the concept of Soft-Weighted
Space-Time Transmit Diversity (SW-STTD) was suggested. In
SW-STTD, relative weighting factors are imposed on the
signals transmitted from the antennas A1 and A2. The
stronger antenna (as measured from the CPICH) is set to
have the larger weight. The CPICH power ranking can be
signaled with 1 bit/slot feedback as specified in A.
Hottinen et al, „Transmit diversity by antenna selection in
CDMA downlink", Proc. IEEE International Symposium of
Spread Spectrum Techniques and Applications (ISSSTA), Sun
City, South Africa, September 1998. For optimal reception,
the receiver needs to know precisely the weights that are
applied at the transmitter. To achieve this, STTD
processing is used in decoding the SW-STTD transmission at
the terminal, thus applying effectively equal gain
combining to the two transmit antennas. Furthermore, the
transmit weight may be changed based on two successive

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feedback commands rather than for each command
independently. For example, when the base station estimates
feedback bits to be [1 1] or [0 0], the transmit gains are
set to [g1 g2], where g1 > g2 or g1 < g2, respectively.

5   When the successive feedback bits are different, i.e. [1 0]
or [0 1], equal power (STTD) transmission is applied, where
g1 = g2. For simplicity, the actual values of the
asymmetric weights may be fixed e.g. to $\sqrt{0.8}$ and $\sqrt{0.2}$,
which are applied also in the above TxAA mode 2. The

10   channel estimate is obtained by filtering the CPICH of the
two antennas, as in the open-loop mode.

In the IMT-2000 specifications, a two-dimensional space-
time code and a closed-loop feedback-based array control

15   are applied as described e.g. by S. M. Alamouti, „A simple
transmit diversity technique for wireless communications",
IEEE Journal on Selected Areas in Communications, Vol. 16,
No. 8, pp. 1451-1458, October 1998. The current concept is
defined for a two-element array (at the base station) which

20   does not require any array calibration. The feedback
control is signaled from each terminal and individual
channel-matched „beams" are transmitted to minimize the
transmit power while meeting the signal-to-interference
requirements. The gains achievable by the feedback mode are

25   significant (when compared to open-loop or single-antenna
transmission) especially in low mobility environments.

Extensions to the above two-element concepts are considered
in order to further increase the system capacity in low

30   mobility environments. While many of these extensions are
straightforward, most of them are applicable only in very
low mobility environments, since the accuracy (or delay) of
the feedback signaling is often compromised.

35

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SUMMARY OF THE INVENTION

It is therefore an object of the present invention to
provide a method and system for transmit diversity or
5   transmit beamforming, by means of which the system capacity
can be increased.

This object is achieved by a method for performing a
transmit diversity transmission of a transmission signal
10   via an antenna array to a receiving means of a wireless
communication system, said method comprising the steps of:
dividing said transmission signal into at least two signal
parts;
transmitting said at least two signal parts by using
15   transmission beams of at least two subarrays of said
antenna array; and
controlling the transmission beam of at least one of said
at least two subarrays at least in part based on a feedback
information received from said receiving means.
20

Furthermore, the above object is achieved by an system for
performing a transmit diversity transmission of a
transmission signal via an antenna array to a receiving
means of a wireless communication system, said system
25   comprising:
dividing means for dividing said transmission signal into
at least two signal parts;
transmitting means for transmitting said at least two
signal parts by using transmission beams of at least two
30   subarrays of said antenna array; and
control means for controlling the transmission beam of at
least one of said at least two subarrays at least in part
based on a feedback information received from said
receiving means.
35

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Accordingly the transmission signal is transmitted via
several beams using an antenna array with more than two
antennas, e.g. at least two subarrays, by dividing the
transmission signal into two signal parts to split the
5   transmission between beams. At least one of the beams is
optimized based on a feedback received from the receiving
end of the wireless communication system. Thereby, open-
loop diversity (space-time division of the transmission
signal) and closed-loop diversity (feedback-controlled
10   beam) are combined in the transmit diversity concept. The
subarrays do not need any sufficient spatial-separation and
even do not have to be uncorrelated. The idea is to use
three or more transmit elements belonging to the same
array, correlated or not, to form two (ore more) beams,
15   which are optimized. Thus, the transmit diversity concept
according to the present invention combines feedback
signaling and space-time block codes or any other method
for dividing signals into two or more parts with a multi-
antenna transmission, to thereby achieve a significant
20   feedback gain in the multi-antenna transmission even with
non-maximal amounts of feedback. Thereby, the system
capacity can be increased without increasing the capacity
of the feedback signaling.

25   Preferably, pilot control means are provided for generating
pilot signals transmitted via pilot channels of
predetermined antenna elements of the at least one of the
at least two subarrays. Thereby, the terminal or mobile
station does not need to know the architecture of the
30   transmitter at e.g. the base station, but only receives
signals via certain probing or pilot channels. It is then
up to the transmitter at the base station to interpret the
corresponding feedback signals of the pilot channels
correctly. The pilot control means may be arranged to
35   change at least one of the predetermined antenna elements
between slots of the transmission signal according to a

predetermined hopping pattern. Thereby, the terminal or
mobile station is able to measure the channels of all
antenna elements based on measurements using only a few
(e.g. two) pilot sequences. The hopping pattern may be
5   changed in dependence on the channel characteristics of the
transmission channel. For example, in very slowly varying
channels, at least one pilot sequence may hop to a
different transmitting element after multiple slots, or
after each frame. It is to be noted that the terminal does
10   not need to know from which antenna element the pilots are
transmitted. Given any pilot hopping pattern, the base
station may interpret the received signals in a correct way
for each terminal.

15   Alternatively, the feedback information may be generated
based on a channel measurement using pilot channels of each
antenna of the at least one of the at least two subarrays,
wherein the pilot channels may be code-division-multiplexed
channels. Thereby, all downlink channels can be estimated
20   simultaneously, such that feedback delay can be reduced.

The feedback information may comprise M-1 feedback weights
used to control the relative weights between M antenna
elements of the at least one of the at least two subarrays.
25   In this case, the feedback weights may be filtered after
reception at the transmitter. Thus, only a small change is
required to the current WCDMA specifications, and the
concept can be used without considering any antenna
calibration, since only relative weights are used.
30
Alternatively, the feedback information may be used to
determine a transmit direction and/or weight jointly for
all elements of the at least one of the at least two
subarrays, wherein the same relative phase is used between
35   neighboring antenna elements. Thus, only one coefficient is
signaled to the network, which reduces control delay. The

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relative weight is then used at the transmitting side to
control the signals supplied to neighboring transmitting
elements.

5   As a further alternative, the feedback information may
comprise a weight information of a part of the antenna
elements of the at least one of the at least two subarrays,
wherein the weight information of the remaining part of the
antenna elements is interpolated. Thus, only a reduced

10   number of feedback parameters are required, since the
remaining parameters are obtained by interpolation at the
transmission side. Interpolation techniques are very
beneficial when the antennas can be assumed to be
correlated.

15

The division of the transmission signal can be performed by
using any space-time transmit diversity processing, delay
diversity processing, space-time trellis coding, coded
substreams or space-time block coding. Thus, optimum

20   transmit weights are calculated regardless of antenna
correlation, while low capacity feedback channels may still
be used.

Another transmission beam of another one of the at least

25   two subarrays may be correlated to the transmission beam of
the at least one of the at least two subarrays. This other
transmission beam can then be formed without feedback by
using received uplink signals. Thus, the transmission beams
are a priori constrained in some particular way. The use of

30   constrained or correlated beams allows to reduce the
feedback link capacity and also helps in channel estimation
at the terminal.

The at least two subarrays may each comprise two antenna

35   elements one of which being controlled by a feedback weight
derived from the feedback information. Thereby, any two-

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antenna feedback mode can be used to control two subarrays
with two elements separately.

The feedback information may be a common feedback
5   calculated based on command pilots. Thus, the feedback can
be calculated as a joint feedback command based on the
common pilots, to thereby reduced feedback signaling
capacity.

10   The dividing step may be suppressed and the transmission
signal may be supplied to the antenna array in order to be
transmitted by a single transmission beam, if it is
determined that the signals from/to the antenna elements of
the antenna array are highly correlated. Thereby, a dynamic
15   mode change can be achieved so as to omit the division into
two signal parts in environments where a single beam
transmission leads to a sufficient transmission quality.

Furthermore, the at least two subarrays may comprise
20   overlapping subarrays having at least one antenna element
which belongs to each of the overlapping subarrays. Thus,
one or even all antenna elements of the antenna array may
belong to two or more overlapping subarrays, wherein the
overlapping subarrays are arranged to generate differently
25   directed beams.

BRIEF DESCRIPTION OF THE DRAWINGS

30   In the following, a present invention will be described in
greater detail on the basis of a preferred embodiment with
reference to the accompanying drawings, in which:

Fig. 1 shows a basic block diagram of a known closed-loop
35   transmit diversity system comprising a base station and
mobile station,

Fig. 2 shows a table indicating characteristic parameters
of the known STD and TxAA modes,

5   Fig. 3 shows a basic block diagram of a transmit diversity
system according to the preferred embodiment of the present
invention,

Figures 4A and 4B show time charts of pilot signalings in a
10   switched mode and in a continuos mode, respectively,
according to the preferred embodiment of the present
invention, and

Fig. 5 shows a basic block diagram of an example of the
15   preferred embodiment of the present invention based on two
subarrays each with two antenna elements.

DESCRIPTION OF THE PREFERRED EMBODIMENT

20
In the following, the preferred embodiment of the method
and system according to the present invention will be
described on the basis of wireless transmission between a
base station 10 and a mobile station or terminal 20 of a
25   WCDMA system. According to Fig. 3, the base station 10
comprises an antenna array which is split into a first
subarray SA1 comprising M1 antenna elements and a second
subarray SA2 comprising M2 antenna elements. The antenna
elements of the two subarrays SA1 und SA2 are fed by a
30   transceiver TRX 11 which supplies M1 parallel signals to
the first subarray SA1 and M2 parallel signals to the
second subarray SA2. The parallel signals are generated by
an STTD encoder 13 which divides a downlink signal to be
transmitted from the network to the terminal or mobile
35   station 20 into two signal parts comprising the M1 and M2

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parallel signals, respectively, according to a space-time
coding scheme.

5   The M1 and M2 parallel signals of the two signal parts are
       supplied to the TRX 11 via a weighting unit 12 which
       applies predetermined transmit weights to at least a part
       of the parallel signals. The applied transmit weights may
       be complex weights, i.e. phase and amplitude of the
       parallel signals may be controlled by the weighting unit
10   12. The transmit weights are controlled by a weight
       determination unit 14 which sets the weights for individual
       ones of the parallel signals according to a feedback
       received by the TRX 11 via a corresponding feedback channel
       (e.g. FBI field of DPCCH of the WCDMA system). Individual
15   feedback signals or weights are extracted by a feedback
       extracting unit 12 from the frame sequence received by the
       TRX 11 from the mobile station 20 and supplied to the
       weight determination unit 14. Thus, a closed-loop control
       is provided by controlling the transmit weights of
20   individual ones of the M1 and/or M2 parallel signals based
       on the feedback information received from the mobile
       station 20.

       Additionally, an open-loop control is achieved by the
25   space-time division of the downlink signal in the STTD
       encoder 13, where the channel symbols of the transmission
       signals are divided into two-element blocks or signal parts
       which are transmitted after the weighting processing by the
       two subarrays SA1 and SA2.
30
       It is to be noted that the weight determination unit 14 and
       the weighting unit 12 may be arranged such that only the
       parallel signals supplied to one of the first and second
       subarrays SA1 and SA2 are controlled. In this case, the
35   transmission beam of one subarray is controlled according
       to an open-loop control scheme and the transmission beam of

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the second subarray SA2 is additionally controlled
according to a closed-loop control scheme. Thereby, the
feedback signaling capacity can be reduced.

5   The feedback information is generated at the mobile station
     20 based on channel pilots (CPICH) transmitted from
     predetermined antenna elements of the first and second
     subarrays SA1 and SA2. The supply of the pilot signals to
     the predetermined antenna elements is controlled by a pilot
10   control unit 11 which controls the TRX 11 so as to supply a
     corresponding pilot or training sequence to the respective
     pilot channels of the signals supplied to the predetermined
     antenna elements.

15   The mobile station 20 comprises a transceiver TRX 21
     arranged to receive the signals transmitted from the
     antenna elements of the first and second subarrays SA1 and
     SA2 and to supply the received and superposed signals to a
     STTD decoder 25 which decodes or combines the received
20   parallel signals or signal parts in order to obtain the
     original downlink signal, wherein the combined closed and
     open-loop transmit diversity scheme leads to a considerable
     diversity gain.

25   Furthermore, the mobile station 20 comprises a pilot
     extraction unit 22 arranged to extract or filter the pilot
     signals transmitted by the predetermined antenna elements
     via the pilot channels. The extracted pilot signals (e.g.
     pilot or training sequences) are supplied to a channel
30   estimation unit 23 which performs a channel estimation
     according to known estimation procedures based on the pilot
     signal. The channel estimations are supplied to a
     quantization unit 24 which may operate according to one of
     the known closed-loop transmit diversity schemes, e.g. STD,
35   TxAA modes 1 and 2, and SW-STTD).

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The quantized feedback information or parameters (e.g. as
indicated in Fig. 2) are supplied to the TRX 21 in order to
be transmitted via the corresponding feedback channel (e.g.
FBI field of the DPCCH) to the base station 10. Thus, the
5   feedback is based on a quantizing of the measurement or
estimation result obtained by the channel estimation unit
23.

It is to be noted that WCDMA terminals usually support only
10   two measurement channels, however this is not critical,
since the mobile station or terminal 20 does not need to
know the architecture of the base station 10, but only
faces certain probing channels. It is then up to the base
station 10 to interpret the received feedback correctly.
15

In case the measurements at the mobile station 20 are based
on two pilot channels, i.e. the mobile station 20 is
capable of probing two pilot channels, two orthogonal codes
or training sequences may be transmitted from two
20   predetermined antenna elements of the first and second
subarrays SA1 and SA2. Thus, pilot signals are transmitted
only from two of the total number of antenna elements of
the two subarrays SA1 and SA2. This may be accomplished by
arranging the pilot control unit 11 so as to fix two
25   antenna elements and transmit continuously from these two
antenna elements. Preferably, the predetermined antenna
elements may be arranged at the edges of the respective
subarray. However, it is to be noted that any two antenna
elements can be used.
30

Alternatively, the pilot control unit 11 can be arranged to
change at least one antenna element between successive
slots. For example, during a first slot, antenna elements
A1 and A2 transmit pilots 1 and 2, during a second slot,
35   antenna elements A1 and A3 transmit these pilots, and so
on. This enables the mobile station 20 to measure the

channels of all antenna elements while measurements or
estimations are performed using only two pilot sequences.
Furthermore, when one pilot channel is fixed to the antenna
element A1, the mobile station 20 can estimate this channel
5   continuously. However, any hopping pattern can be used for
switching the second pilot.

Figure 4A shows a time diagram indicating a predetermined
hopping pattern within a frame formed by 15 slots, which
10 may be used in very slowly varying channels. The pilot 2
can hop from the antenna element A2 to the antenna element
A3 and back after one slot, multiple slots, or after each
frame. It is again noted that the base station 20 does not
necessary need to know from which antenna element the pilot
15 signals are transmitted, as long as the base station 10
knows the hopping pattern. Then, given any pilot hopping
pattern, the base station 10 is able to interpret the
received feedback signals in the correct way for each
mobile station 20. The hopping pilot enables the mobile
20 station 20 to calculate a feedback information θ of the
respective transmit beam of the corresponding subarray
based on the following equation:

$$\theta = \arg\min_{0} \| \hat{a} - w(\theta) \| \tag{1}$$

25

where $\hat{a}$ denotes the estimation of the downlink channel and
w the parametrized array weight vector. Effectively, the
mobile station 20 calculates the best fit between the
measured channel (measured from the probing channels) and a
30 parameterized channel manifold. Having calculated this
feedback information θ, it is quantized in the quantization
unit 24 and signaled back to the base station 10. The
weight determination unit 14 of the base station 10 then
determines and modifies the transmit weights accordingly,
35 after the feedback signal has been detected or extracted by

the feedback extraction unit 12. Thus, the multi antenna
transmit diversity scheme can be reduced to a current two-
element transmit diversity concept with two antennas.

5   Alternatively, the pilot control unit 11 may be arranged to
     transmit separate pilot signals via the pilot channels of
     all antenna elements of the respective subarray, so that
     all downlink channels can be estimated simultaneously. To
     achieve this, code-division-multiplexed pilot signals can
10   be transmitted via the limited number of pilot channels
     which can be measured or estimated at the mobile station
     20.

     Fig. 4B shows a time diagram of such a continuous pilot
15   transmission via code-division-multiplex pilot channels.
     Three pilots 1 to 3 are simultaneously transmitted via the
     pilot channel using different code sequences.

     The transmitted feedback information may be used to define
20   relative weights between all antenna elements of the
     respective subarray. Thus, in case of M controlled antenna
     elements, M-1 feedback weights are signaled sequentially to
     the base station 10 in order to control the relative
     weights between all antenna elements. Thereby, only a small
25   change to the current WCDMA system is required. However,
     due to the long control delay required for transmitting all
     relative weights, this closed-loop control is only
     beneficial for very slowly fading channels.

30   According to a parameterized/structured-array beam-forming
     concept, a feedback signal may be used which jointly
     determines the transmit „direction" or weight for all
     antenna elements of a respective subarray. The same
     relative phase between all neighboring antenna elements is
35   then used, and this phase is calculated by the mobile
     station 20 based on command channel measurements using two

or more pilot channels. The transmit beam, parameterized by the feedback information θ, is then given by the following equation:

$$
5 \quad \underline{w}(\theta) = \begin{bmatrix} 1 \\ e^{(j2\pi d\sin(\theta))/\lambda} \\ \vdots \\ e^{(j2\pi(M-1)d\sin(\theta))/\lambda} \end{bmatrix} \tag{2}
$$

wherein the terms in brackets indicate the complex weights w_1, w_2, ... w_M, respectively, of the antenna elements of the controlled subarray, d denotes the distances between

10 neighboring antenna elements, λ denotes the wavelength of the parallel transmission signals, and M denotes the number of antenna elements in the subarray. Thus, only one coefficient is signaled to the network (base station 10), which leads to a reduced control delay. However, in certain

15 channels, the parameterized model may not match the transmission channel. Therefore, an inherent trade-off between control delay and weight parameterization is usually given.

20 It is to be noted, that the transmit weights may as well be determined so as to control the gain of different antenna elements. Then, the above equation (2) can be written as

$$
\underline{w}(\theta) = \begin{bmatrix} 1 \\ g_2 e^{(j2\pi d\sin(\theta))/\lambda} \\ \vdots \\ g_M e^{(j2\pi(M-1)d\sin(\theta))/\lambda} \end{bmatrix} \tag{3}
$$

25

wherein the gain parameters g_1, g_2, ... g_M define the length of the complex weight arrow in the complex plain. Thus, the transmission power supplied to individual antenna element can be controlled by the weighting unit 12. It is

30 to be noted that equation (1) may be calculated for each

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slot using the parametrization given by equations (2) or
(3).

5   In particular, when the WCDMA FSM message is used with both
gain and phase control bits, g_1 and g_M can be assigned
according to the feedback gain information, while the gains
$g_2,...g_{M-1}$ for the other antenna elements are interpolated
e.g. in a linear manner. For example, if the gain g_1 is
signaled to the antenna A1 and the gain g_M is signaled to
10   the antenna AM, the power or gain for the other antenna
elements arranged between the antenna elements A1 and AM
can be set e.g. according to the following equation

$$g_m = g_1 + (m-1)(g_M - g_1)/(M-1) \tag{4}$$

15

wherein m indicates the number or index of an individual
antenna element for which the gain is interpolated.
Naturally, the gains can be normalized in any desired way.
However, it is to be noted that any interpolation can be
20   applied to determine the remaining gains, e.g. quadratic,
or cubic normalization.

Interpolation techniques are preferred in cases where the
antenna elements can be assumed to be correlated. The
25   antenna correlation depends in practice on a number of
issues. Typically, the correlation is high and there is
little spatial aliasing, when the antenna elements are
close to each other (e.g. half the wavelength).
Furthermore, the channels faced by the antenna elements are
30   less correlated in the presence of a multipath propagation.
Multipath-rich environments are likely to suffer from
performance degradation, since the interpolated weights may
not add up coherently to the received signal at the base
station 20. This problem can be alleviated by enabling the
35   mobile station 20 to probe all M channels e.g. with a
hopping pilot.

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It is as well possible to feedback M-1 weights to the base station 10 and let the weight determination unit 14 decide how to filter these weights. If these successive weights
5   are transmitted e.g. sequentially, the weight determination unit 14 can decide based on received statistics if these weights are correlated and then fit an appropriate linear or non-linear model to enhance the weights. For example, if the parallel signals are transmitted with a phased array
10   with elements close to each other, the feedback signals describing neighboring phase offsets (relative transmit weights) would be highly correlated. Thus, the weight determination unit 14 can filter these relative feedback weights in order to determine a transmit weight jointly for
15   all M antenna elements. In this case, the mobile station 20 operates without any knowledge of the antenna structure at the base station 10, and the base station 10 determines the filtering operation based on receipt signal statistics (e.g. correlation of antenna elements), or based on an a
20   priori knowledge of the antenna structure. However, any method which enables the mobile station 20 to calculate M-1 feedback signals can be used for defining the downlink probing/pilot channels.

25   Thus, the preferred embodiment of the present invention allows to calculate optimum transmit weights regardless of antenna correlation, while still using a low capacity feedback channel, enabled by a parameterized array manifold. The signal is separated into (at least) two
30   signal parts of parallel signals, where each signal part is separable by a suitable decoding or detection technique. A feedback information is determined for at least one subchannel. The subchannel may be defined as M different antennas, or M different linear combinations of signals
35   transmitted by M' different antenna elements. M and M' need not necessarily be the same. Besides the described STTD

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scheme, any other technique for dividing the signal into
any number of signal parts is possible, e.g. delay
diversity, space-time trellis coding, coded substreams,
space-time block coding with more than two transmitting
5   antennas, etc. Furthermore, assuming that the first signal
is transmitted using M1 antenna elements and the second
signal part is transmitted using M2 antenna elements,
partly or even fully overlapping subarrays may be used,
i.e. M1 + M2 > M. That is, one antenna element or even all
10   antenna elements may belong to both subarrays. In this
case, the subarrays would generate differently directed
beams.

In case beam-space STTD is used, the received signal is
15   given by the following equation

$$
\begin{bmatrix} z[2n] \\ z[2n+1] \end{bmatrix} = \begin{bmatrix} s[2n] & s[2n+1] \\ -s^*[2n+1] & s^*[2n] \end{bmatrix} \begin{bmatrix} w_1^t \\ w_2^t \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \\ \vdots \\ h_M \end{bmatrix} + \begin{bmatrix} n[2n] \\ n[2n+1] \end{bmatrix} \tag{5}
$$

wherein h_m denotes a channel coefficient between the mobile
20   station 20 and the antenna A_m, and w_j^t denotes a feedback

weight transmitted at at time instant t via feedback
channel j, the matrix describes the known STTD coding
processing, and the added signal n describes the received
noise.
25

According to the preferred embodiments, at least one of the
beams transmitted by the two subarrays SA1 and SA2 is
optimized using the feedback information from the mobile
station 20 to the base station 10.
30

According to a constrained beam forming concept, the two
beams transmitted from the subarrays SA1 and SA2,

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respectively, are a priori constrained in a particular way.
The use of such constrained beams allows to reduce the
feedback link capacity. To achieve this, one of the two
beams may be controlled so as to be always orthogonal or
5   correlated in a known way to the other beam, wherein the
one beam is controlled by the feedback information possibly
taking into account the known beam correlations. In a
4-antenna realization, the first beam may be a priori
restricted to be e.g. in the subspace spanned by antenna
10   elements A1 and A2, and the second beam would be in the
subspace spanned by the antenna elements A3 and A4. In this
example, at least one of the beams is changed based on
feedback. For example, the second beam need not be changed
at all by feedback, if the first beam is modified. The
15   first beam may be optimized by using any feedback mode. In
a corresponding 3-antenna realization, the weights w_1 and
w_2 for the first beam and second beam, respectively, could
be chosen according to the following equations

$$
20 \quad \underline{w}_1 = \begin{bmatrix} 1 \\ e^{j\theta} \\ 0 \end{bmatrix}, \quad \underline{w}_2 = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}, \quad\quad\quad\quad (6)
$$

wherein each vector element denotes a weight supplied to
one of the three antennas A1 to A3. Thus, the first beam is
controlled by supplying an uncontrolled signal to the
25   antenna element A1, a phase-controlled signal to the
antenna element A2, and no signal to the antenna element
A3. The second beam is generated by solely supplying an
uncontrolled signal to the antenna element A3. Any two-
antenna feedback mode may be used for controlling the first
30   beam.

According to a more complex realization (for any number of
antenna elements), the first beam may have components in
all antenna directions, or at least M1 + M2 > M. The

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feedback information may be used to control any number of
weights from 1 to 2(M1 - 1), utilizing a generalization of
any 2-antenna feedback mode to optimize the beam in
question. The other beam is automatically kept orthogonal
5   to the controlled beam. This can be achieved by a
corresponding weight control performed in the weight
determination unit 14. This concept may preferably be
combined with the SW-STTD concept initially described, i.e.
when the quality of the feedback is judged to be good and
10   the controlled beam approaches an optimum beam, the weight
of this beam is increased.

According to another example, the first beam may be
selected to transmit to all directions covered by M
15   elements, using e.g. a space-time block code, and the
second beam may be controlled by feedback according to any
of the initially described weight control techniques.
Furthermore, one dimension (parallel signal) of the space-
time code can be assigned to Tx-AA (with feedback-based
20   weight control) and the remaining M-1 dimensions (parallel
signals) may be assigned to conventional space-time
transmissions (leading to a diversity M-1 for space-time
transmission alone). The transmit power of these two
parallel transmissions can be controlled either with or
25   without feedback.

According to a partially blind beam forming concept, a
diversity beam may be formed using received uplink signals
without explicit feedback at the base stations 10, while
30   another beam can be optimized using feedback. The dynamics
of the diversity beam may differ from those of the
feedback-optimized beam. For example, the blind diversity
beam may changed at frame resolution (e.g. 10 ms) and the
feedback beam may changed 15 times during one frame (i.e.
35   with each slot).

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Fig. 5 shows a further example of the preferred embodiment
where each of the first and second subarrays SA1 and SA2
comprises two antenna elements. The antenna elements A1 to
A4 are fed by respective transceivers TRX 111 to 114.
5   Furthermore, weighting units 12 are provided in the
transmission paths leading to the antenna elements A2 and
A4, wherein the weight determination unit 13 is arranged to
control the weighting units 12 so as to apply a
predetermined weight to the parallel signal supplied to the
10   antenna element A4 and another predetermined weight to the
parallel signal supplied to the antenna element A1. The
weighting units 12 may comprise known controllable
attenuation elements or networks and/or known controlled
delay or phase shifting networks or elements, so as to
15   achieve the required gain and/or phase shift. In the
example shown in Fig. 5, the two subarrays SA1 and SA2 each
with two antenna elements A1, A2 and A3, A4, respectively,
can be controlled separately using any two-antenna feedback
mode. The transmission from the antenna elements A1 and A3
20   is performed with a weight "1", while the phases and/or
gains of the antenna elements A2 and A4 are controlled via
feedback. This can be described by the following equations:

$$
\underline{w}_1 = \begin{bmatrix} 0 \\ 0 \\ 1 \\ e^{j\theta_1} \end{bmatrix}, \quad \underline{w}_2 = \begin{bmatrix} 1 \\ e^{j\theta_2} \\ 0 \\ 0 \end{bmatrix} \tag{7}
$$

25

where $\underline{w}_1$ indicates the complex weight vector used to
control the first beam, and $\underline{w}_2$ indicates the complex weight
vector used to control the second beam. As can be gathered
from the above equation, the first and second beams are
30   orthogonal, since different dimensions of the vectors are
controlled, i.e. a change of the antenna elements A1 and A2
leads to a change in the second beam but not to a change in
the first beam. The relative gains of the subarrays SA1 and

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SA2 may be controlled in place or in addition to the
control of the phases.

5   The feedback information can be calculated in such a manner
      that a joint feedback command is obtained based on common
      pilots, whereas the signal parts are transmitted
      individually from the subarrays SA1 and SA2. For example,
      the beams may be chosen as defined in equation (6), but
      only one common feedback information may be transmitted
10   from the mobile station 20 to the base station 10. Usually,
      the aim of the feedback is to maximize the sum of the
      squared receiving powers of the two beams. Then, e.g.
      $\theta_1 = \theta_2$ may be applied in the above equation (7).

15   According to a further example, dedicated beams could be
      formed based on common pilots of the antenna elements A1
      and A4. Then, the first signal part may be transmitted from
      these two elements (forming the first subarray SA1), and
      the second signal part may be transmitted from the middle
20   antenna elements A2 and A3 (forming second subarray SA2)
      using the same relative phase offset between all
      neighboring elements. Hence, the phases for the middle
      antenna elements A2 and A3 are interpolated from the other
      elements. In this case, it is assumed that the antenna
25   elements A1 to A4 are placed at equal distances and that
      the antenna elements A1 and A4 are arranged at the edges of
      the whole antenna array.

      In the preferred embodiment, the STTD encoder 13 may be
30   arranged so as to provide a dynamic mode change based on
      the correlation of the signals transmitted from or received
      by the antenna elements of the subarrays SA1 and SA2. This
      determination may be performed at the mobile station 10 or
      at the base station 20. In particular, when it is
35   determined that the signals are highly correlated, the
      division into the two signal parts can be omitted or

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suppressed and one of the coded or divided signal parts can
be transmitted using a single beam generated by M elements.
A weight verification can be added such that the mobile
station 20 may derive whether beam diversity or single-beam
5   transmission is applied.

In summary, the present invention relates to a method and
system for transmitting a transmission signal via an
antenna array to a receiving means 20 of a wireless
10   communication system, wherein a transmission signal is
divided into at least two signal parts which are
transmitted by using transmission beams of at least two
subarrays SA1, SA2 of the antenna array. The transmission
beam of at least one of the at least two subarrays SA1, SA2
15   is at least in part controlled based on a feedback
information received from the receiving means 20. Thus,
several beams are generated using an antenna array with
more than two antennas, wherein an open-loop diversity is
used to split the transmission between the beams, and a
20   closed-loop feedback-based diversity is used to optimize
the beams, as well as possibly the division of power
between the beams. Thereby, the amount of feedback can be
controlled so as to achieve significant feedback gain in a
multi-antenna transmission even with non-maximal amounts of
25   feedback.

The present invention is not limited to the above preferred
embodiments but can be applied to any multi-antenna
transmitter in order to provide an increased system
30   capacity. As already mentioned, any kind of division scheme
can be used, provided the downlink signal can be recovered
at the mobile station 20. The feedback signaling can be
performed according to any signaling or quantization
concept suitable for obtaining transmit weights at the base
35   station 10.

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Moreover, the present invention may be applied to any
wireless communication system comprising a transmit
diversity or transmit beam forming concept used between a
transmitting element and at least one receiver. Therefore,
5   the above description of the preferred embodiment and the
accompanying drawings are only intended to illustrate the
present invention. The preferred embodiment of the
invention may be varied within the scope of the attached
claims.

10

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Claims

1.   A method for transmitting a transmission signal via an
5   antenna array to a receiving means **(20)** of a wireless
communication system, said method comprising the steps of:
        a)   dividing said transmission signal into at least
two signal parts;
        b)   transmitting said at least two signal parts by
10   using transmission beams of at least two subarrays **(SA1,
SA2)** of said antenna array; and
        c)   controlling the transmission beams of at least
one of said two subarrays **(SA1, SA2)** at least in part based
on a feedback information received from said receiving
15   means **(20)**.

2.   A method according to claim 1, wherein said feedback
information is generated based on a channel measurement
using pilot channels of predetermined antenna elements of
20   said at least one of said at least two subarrays **(SA1,
SA2)**.

3.   A method according to claim 2, wherein said
predetermined antenna elements are fixed and controlled to
25   transmit continuously via said pilot channels.

4.   A method according to claim 3, wherein said
predetermined antenna elements are arranged at the edges of
said at least one of said at least two subarrays **(SA1,
30   SA2)**.

5.   A method according to claim 2, wherein at least one of
said predetermined antenna elements changes between slots
of said transmission signal according to a predetermined
35   hopping pattern.

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6.   A method according to claim 5, wherein said hopping
pattern depends on the channel characteristics of the
transmission channel.

5

7.   A method according to claim 1, wherein said feedback
information is generated based on a channel measurement
using pilot channels of each antenna element of said at
least one of said at least two subarrays (SA1, SA2),
10   wherein said pilot channels are code-division-multiplexed
channels.

8.   A method according to claim 1, wherein said feedback
information comprises M-1 feedback weights used to control
15   the relative weights between all M antenna elements of said
at least one of said at least two subarrays (SA1, SA2).

9.   A method according to claim 8, wherein said feedback
weights are filtered after reception at the transmission
20   side (10).

10.   A method according to claim 1, wherein said feedback
information determines a transmit direction and/or weight
jointly for all antenna elements of said at least one of
25   said at least two subarrays (SA1, SA2), wherein the same
relative phase is used between neighboring antenna
elements.

11.   A method according to claim 1, wherein said feedback
30   information comprises a weight information for a part of
the antenna elements of said at least one of said at least
two subarrays (SA1, SA2), wherein the weight information
for the remaining part of said antenna elements is
interpolated.

35

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12. A method according to any one of the preceding claims, wherein said transmission signal is divided by using a space-time transmit diversity processing, a delay diversity processing, a space-time trellis coding, coded substreams,
5   or a space-time block coding.

13. A method according to claim 1, wherein another transmission beam of another one said at least two subarrays **(SA1, SA2)** is correlated to said transmission
10 beam of said one of said at least two subarrays **(SA1, SA2)**.

14. A method according to claim 13, wherein said other transmission beam is formed without feedback by using received uplink signals.
15

15. A method according to claim 1, wherein said at least two subarrays **(SA1, SA2)** each comprise two antenna elements, one of which being controlled by a feedback weight derived from said feedback information.
20

16. A method according to claim 1, wherein said feedback information is a common feedback calculated based on common pilots.

25 17. A method according to any of the preceding claims, wherein said dividing step is suppressed and the transmission is performed by a single transmission beam, if it is determined that the signals from/to the antenna elements of said antenna array are highly correlated.
30

18. A system for transmitting a transmission signal via an antenna array to a receiving means **(20)** of a wireless communication system, said system comprising:
        a)   dividing means **(13)** for dividing said
35 transmission signal into at least two signal parts;

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      b)   transmitting means **(11)** for transmitting said at least two signal parts by using transmission beams of at least subarrays **(SA1, SA2)** of said antenna array; and

      c)   control means **(12, 14)** for controlling the transmission beam of at least one of said at least two subarrays **(SA1, SA2)** at least in part based on a feedback information received from said receiving means **(20)**.

19.   A system according to claim 18, further comprising pilot control means **(11)** for generating pilot signals transmitted via pilot channels of predetermined antenna elements of said at least one of said at least two subarrays **(SA1, SA2)**.

20.   A system according to claim 19, wherein said pilot control means **(11)** are arranged to change at least one of said predetermined antenna elements between slots of said transmission signal according to a predetermined hopping pattern.

21.   A system according to claim 20, wherein said pilot control means **(11)** is arranged to change said predetermined hopping pattern in dependence on the channel characteristics of the transmission channel.

22.   A system according to any one of claims 18 to 21, further comprising feedback extraction means **(12)** for filtering said feedback information and for supplying the filtered feedback information to a weight determination means **(14)** of said control means **(12, 14)**.

23.   A system according to claim 22, wherein said feedback information determines a transmit direction and/or weight jointly for all antenna elements of said at least one of said at least two subarrays **(SA1, SA2)**, and wherein said

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weight determination means **(14)** is arranged to use the same relative phase between neighboring antenna elements.

24.   A system according to claim 22, wherein said weight
5   determination means **(14)** is arranged to interpolate a weight information of a part of the antenna elements of said at least one of said at least two subarrays **(SA1, SA2)**.

10   25.   A system according to any one of claims 18 to 24, wherein said dividing means **(13)** is arranged-to divide said transmission signal by using a space-time transmit diversity processing, a delay diversity processing, a space-time trellis coding, coded substreams, or a space-
15   time block coding.

26.   A system according to claim 18, wherein said control means **(12, 14)** is arranged to correlate another transmission beam of another one of said at least two
20   subarrays **(SA1, SA2)** to said transmission beam.

27.   A system according to claim 26, wherein said control means **(12, 14)** is arranged to form said other transmission beam without feedback by using received uplink signals.
25

28.   A system according to any one of claims 18 to 27, wherein said dividing means **(13)** is arranged to suppress the division and to supply an output signal to said antenna array in order to be transmitted by a single transmission
30   beam, if it is determined that the signals from or to the antenna elements of said antenna array are highly correlated.
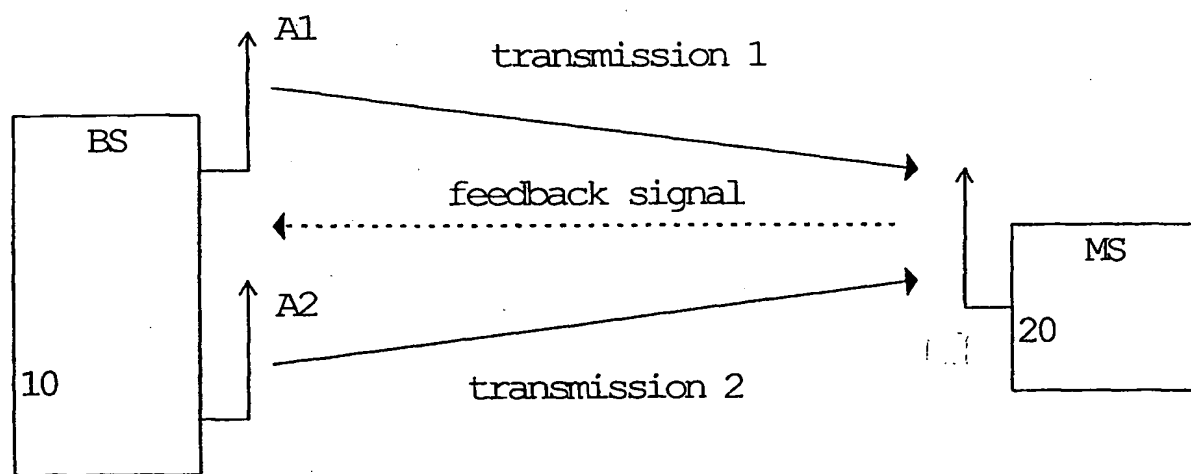
29.   A system according to any one of claims 18 to 28,
35   wherein said at least two subarrays **(SA1, SA2)** comprise

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overlapping subarrays having at least one antenna element
which belongs to each of the overlapping subarrays.

30. A system according to any one of claims 18 to 29,
5   wherein said transmission is performed between a base
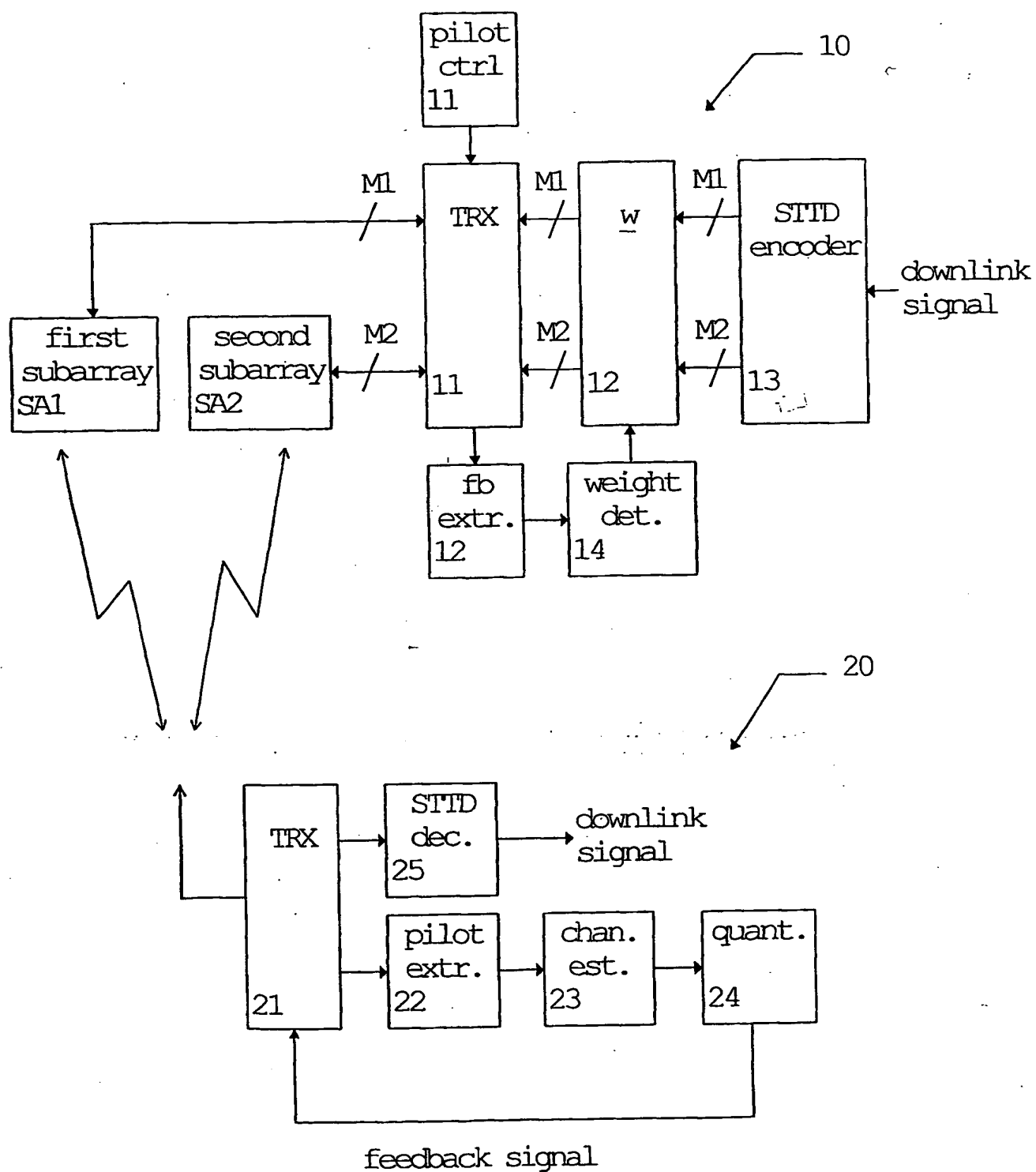station **(10)** and a mobile station **(20)** of a WCDMA system.

prior art

Fig. 1

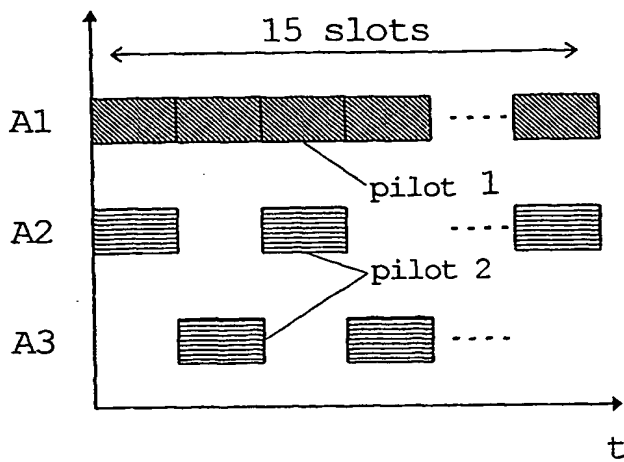| mode	N_{FB}	N_W	feedback bit rate	Na	Np
STD	1	1	1500bps	1	0
TxAA mode 1	1	2	1500bps	0	2
TxAA mode 2	1	4	1500bps	1	3

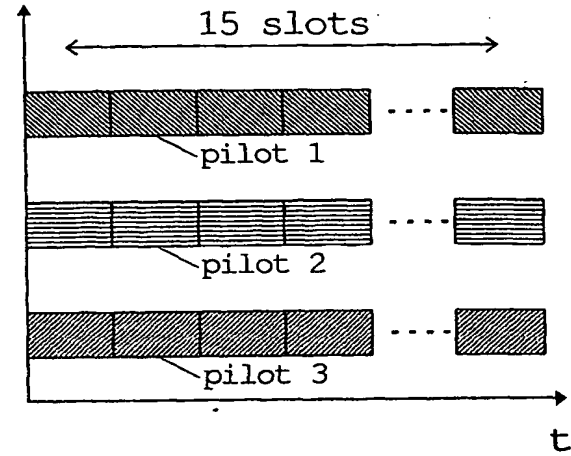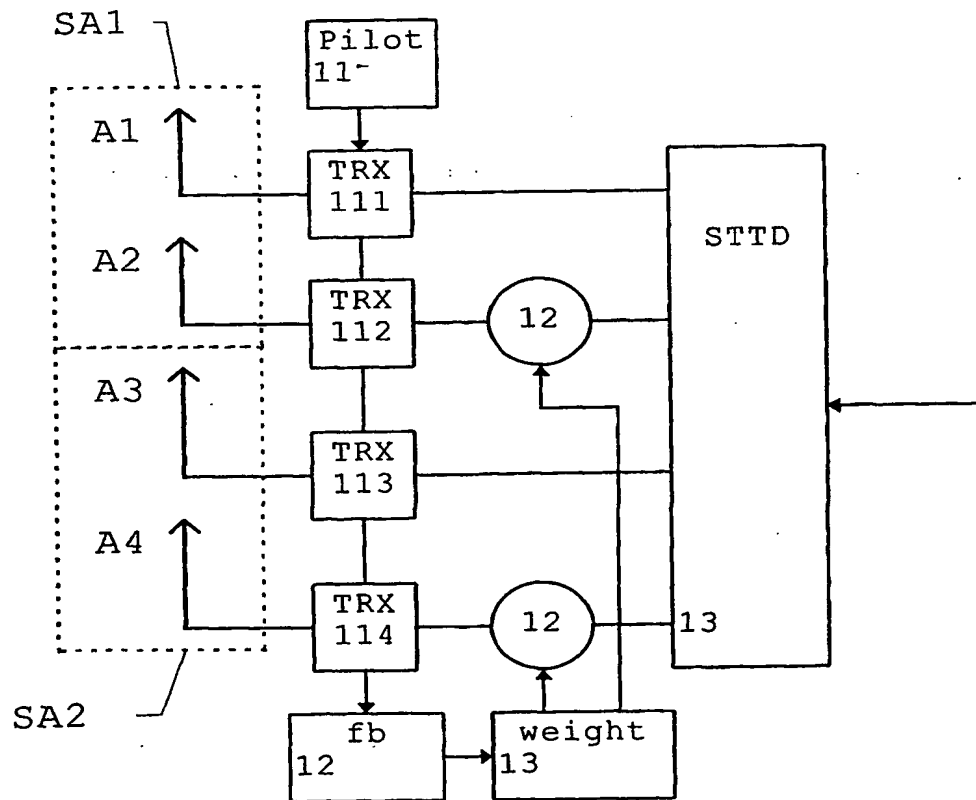**prior art**

Fig. 2

Fig. 3

Fig. 4A

Fig. 4B

Fig. 5

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7   H04B7/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7   H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
E	WO 00 36764 A (NOKIA NETWORKS OY ;WICHMAN RISTO (FI); HOTTINEN ARI (FI)) 22 June 2000 (2000-06-22) abstract page 3, line 1 - line 29 page 5, line 4 - line 31 page 9, line 29 -page 10, line 5 page 11, line 1 -page 15, line 2 -/--	1-3,7,8, 10,12, 13,16, 18,19, 25,30

[X] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 December 2000	21/12/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Lustrini, D

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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